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Assessment of Casualty Transport Equipment and Procedures Aboard U.S. Navy Submarines to Accommodate Anti-Shock Trousers

by

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ABSTRACT

Confined spaces necessitating non-ideal stretcher positioning and the potential for significant transportation times to definitive care combine to make casualty evacuation from a submarine much more onerous than in typical state-side scenarios. Anti-shock garments, while having fallen out of favor in the general community, may provide certain benefits in specific submarine medical evacuation scenarios, such as those involving hemorrhagic shock. A review of pertinent literature is presented as well as an evaluation of both inflatable and non-inflatable anti-shock garments for potential use in the submarine medical community. Both types of garments were found to accommodate submarine casualty egress, with several advantages noted for the non-inflatable variety. Current clinical trials of these newer, non-inflatable devices should be monitored as they may prove applicable to multiple austere military medical environments.

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INTRODUCTION

U.S. Navy submarines present considerable challenges to medical care providers treating trauma while underway. A significant problem is casualty movement within the tight confines of the submarine. The minimal space, narrow passageways, multiple deck levels, and corners require considerable manipulation of the stretcher-bound patient, resulting in head elevation and transfer delay in extraction of the casualty. These difficulties were examined in NSMRL Technical Report 1263[1], "An evaluation of casualty egress and patient stretchers for use on U.S. Navy Submarines." In this report, NSMRL investigators provided the results of casualty movement trials using weighted mannequins restrained in the various stretcher types used aboard submarines. This report found that significant problems could occur when the potential casualty is placed in a vertical position, hoisted up to the hatch, and egressed from the boat, particularly when being moved up through the sail to the bridge for helicopter medevac, a vertical distance of nearly 30 feet. Problems incurred during vertical movement include hemodynamic changes in the patient, manipulation difficulty in the tight confines of the trunk, fit problems with the narrow diameter hatch, and inability of medical responders to perform resuscitation efforts or evaluate the patient.

These issues were evident in 2008 when a submariner incurred a fatal crush injury and pelvic fracture with associated vascular compromise. This patient was maintained with marginal hemodynamic stability, but became unconscious and arrested shortly after being lifted to a vertical position for movement up through the hatch for helicopter medevac.

Anti-shock garments, first developed in the early 1900s and popularized in the Vietnam War may have been of assistance in the above situations. Although anti-shock garments have fallen out of favor in the civilian sectors, where transit times to Level I trauma facilities are often minimal, these devices might be a potential asset in some cases of pelvic fracture and severe hypotension occurring in an austere environment, such as the submarine. Not only are submarines generally quite remote from major treatment facilities, they also present a unique environment in that casualties must be transported in not only the horizontal position, but also vertical and many other angles in-between in order to navigate the tight passageways and ladder wells of the boat, both of which may be partially obstructed by protruding equipment, lockers, brackets or stanchions.

The concept of a pneumatic compression device to augment blood pressure was first developed by surgeon George Crile in 1903 when he used a pneumatic rubber suit to decrease hypotension in patients undergoing head & neck surgery in the seated position [2]. The concept was later used to create "G-suits" for pilots during World War II. Medical use expanded during the Vietnam era when anti-shock suits were employed to help stabilize severely hypotensive patients during 45-minute or longer helicopter transit times until blood replacement and definitive surgery could be performed [3]. With reports of marked improvements in patients with tenuous clinical presentations [3], military anti-shock trousers (MAST), or pneumatic anti-shock garments (PASG), began to be adopted by emergency medicine caregivers in the mid-1970s [4,5]. Initial case series reports showed prolonged survival and sometimes even recovery of severely hypotensive patients both in the military and civilian settings. Based upon these findings, MAST were incorporated into many civilian emergency medicine protocols.

Actual prospective, randomized, controlled trials of the device did not occur until the late 1980s and 1990s. A study by Mattox et al. assessed the usage of MAST versus no MAST in 352 patients suffering from penetrating trauma to the thorax, abdomen, or extremity with systolic blood pressure (SBP) $\leq$ 90mmHg and at least one clinical sign of shock [6]. His surprising results revealed no benefit to MAST usage and potential harm in the way of compartment syndrome and diaphragmatic herniation of abdominal contents. There was a subgroup, however, whose initial SBP was less than or equal to 50 mmHg that did show a trend toward improved survival with MAST. A second Mattox study published in 1989 showed no improvement in survival with MAST usage in chest, abdominal, or neck trauma and that MAST adversely affected cardiac and thoracic vascular injury [7]. Another randomized controlled prospective trial was conducted in 1995 by Chang et al. Here, MAST usage in blunt and penetrating trauma in a medium-sized urban environment was examined in a set of 1075 subjects with SBP $\leq$ 90 mmHg and at least one clinical sign of shock. Penetrating thoracic injuries were found to fair worse with MAST with no difference between groups for other injuries. Interestingly, fewer ER procedures (chest tube, intubation, thoracotomy) were conducted in the MAST group.

An important caveat to these studies is that all were conducted in urban settings where transport times to a Level I trauma facility were relatively minimal. No pelvic injuries were included and each study had to exclude several participants from analysis due to protocol violations (generally in which MAST was forgotten or could not be used). It is possible that subjects who did not receive MAST benefitted from the short urban transit times to definitive care, which would be lacking in an austere environment, such as aboard a submarine. It is also possible that the subject group assessed by these studies (SBP $\leq$ 90mmHg with at least one sign of clinical shock) was not the ideal group for MAST use. A follow-up retrospective review of 142 subjects with severe hypotension (SBP $\leq$ 50 mmHg) conducted by Cayten et al. to further investigate the subgroup trend identified by Mattox's 1986 study found that MAST usage imparted a higher survival rate for this group ($p=0.055$) [8]. The study noted that no survival benefit was found with SBP > 50mmHg and that subjects actually fared worse if initial SBP>70mmHg. Thus, appropriate clinical indication for usage may be far more specific than originally thought.

As a result of these reports, significant controversy regarding the use of pneumatic compression trousers developed. A Cochrane Review was conducted focusing primarily on the Mattox and Chang studies which warned of the lack of demonstrated benefit and possible harm with MAST usage. The review included the caveat that "… due to the poor quality of the trials, conclusions should be drawn with caution" [9]. Similarly a position paper released by the National Association of EMS Physicians urged caution against the ubiquitous use of MAST and gave specific guidelines as to where they might impart benefit, such as in the event of hypotension secondary to a rupture abdominal aortic aneurysm or suspected pelvic fracture as well as severe traumatic hypotension [10]. They further went on to delineate a long list of situations where MAST use was contraindicated, as in cases of cardiogenic shock, tamponade, myocardial infarction, asystole, and pulmonary edema.

Currently, medical providers are reluctant to use pneumatic anti-shock garments [10]. However, a reusable, lightweight neoprene and Velcro suit was developed in 1971 by Dr. Ralph Pelligra (NASA/Ames) and subsequently received FDA device approval in 1991 by the Zoex Corporation (http://www.zoexniasg.com/).This non-pneumatic anti-shock trouser has been evaluated in remote medical areas, such as Egypt, Nigeria, and Pakistan. Several clinical trials examined its use for obstetric hemorrhage in austere environments, with positive results on both maternal morbidity and mortality [11-17].

Two case series reports from Pakistan in the early 2000s noted remarkable improvement in women with severe shock from obstetrical hemorrhage within minutes of application of the non-inflatable anti-shock garment (NIASG) [16,17]. Subsequent prospective pre-intervention/intervention trials of the NIASG by Miller in both Egypt and Nigeria revealed improvements in blood loss and morbidity in the NIASG groups with no adverse events [11,12]. Combining these two studies yielded enough subjects (835) to address mortality, which decreased from 6.3% to 3.5% with the NIASG use. The authors further noted a 50% decrease in blood loss, a decrease in severe morbidity from 3.7% to 0.7%, and a decrease in emergency hysterectomy from 8.9% to 4.0% in the NIASG group, despite this group's being in worse condition on study entry [14]. No adverse effects, such as compartment syndrome or exacerbated lactic acidosis, were noted even with over 36 hours of continued use. [One female experienced dyspnea within minutes of NIASG application and the device was promptly removed. It was later determined that she had undiagnosed mitral stenosis which became symptomatic with the NIASG [16].] Advantages of the NIASG (over the MAST) are that it affords full perineal access, thus groin and rectal exams are still possible with the garment in place; it can be applied quickly by those with minimal medical training; and it requires no pressure pumps or extra equipment beyond the neoprene garment itself. Currently, a clustered randomized controlled trial is underway in Zambia and Zimbabwe to more rigorously test the effect of the NIASG upon mortality and severe morbidity in maternal hemorrhage and hypovolemic shock (NCT: 00488462). Data collection for this effort is estimated to be completed in May 2012. To date, trials of the NIASG are limited to post-partum hemorrhage.

Given that the submarine environment has more in common with medically remote areas than urban centers, having a tool to act as a bridging device to stabilize patients with severe hemorrhagic shock and pelvic trauma until they can be transported to definitive care would be greatly advantageous. It would also be quite useful in egressing a patient from a submarine where a casualty cannot be kept horizontal at all times and transport in the vertical position may exacerbate hemodynamic instability. In light of these observations and actual submarine casualties, this study was designed to assess the feasibility of MAST or NIASG usage in a submarine medevac situation when a patient must be transported from the extremes of the boat to the center and then hauled up and out the submarine sail for helicopter transport. In addition, a winch system used to lift casualties up and out the sail was also evaluated.

OBJECTIVES

The objective of this project was to assess the feasibility of anti-shock garment usage, in terms of casualty egress, during medevac from a U.S. submarine. In addition, a winch system marketed by Spec Rescue International was also tested for potential use to assist egress at the forward, aft, and sail hatches.

METHODS

Investigators conducted a literature review to obtain background information regarding the current application of anti-shock garments in the medical community. In researching traditional anti-shock garments (military anti-shock trousers, or MAST), a newer, non-inflatable anti-shock garment (NIASG) was also identified. Representative pairs of both garments, MAST and NIASG, were obtained for evaluation.

Mannequins were fit-tested with both types of anti-shock garments to determine time to apply, ease of use, and relative bulkiness of the applied device. Mannequins outfitted with each type of garment were then placed on each of the main stretcher types found aboard U.S. Navy submarines: the Search-and-Rescue (SAR) litter, the Reeves Sleeve II, and the Miller Board to see if each could accommodate the additional bulk created by the anti-shock garment.

Following the basic test protocol described above, investigators requested the availability of a representative submarine at Naval Submarine Base New London. A LOS ANGELES Class submarine served as a testing platform. Ability to maneuver a simulated casualty (mannequin) outfitted with the anti-shock garment through the submarine’s passageways, ladders, and hatches for ultimate egress and medevac was evaluated.

Additionally, the Haul-Safe winch system (Spec Rescue International; 2697 International Parkway; Virginia Beach, VA 23452) was also evaluated for potential usability at the forward, aft, and sail hatches for casualty extraction from the submarine. Time for set-up, ease and safety of use, and relative bulkiness were considered.

Figure 1. Carrying cases for NIASG (left) and MAST (right).

Figure 2. MAST (left) and NIASG (right).

Figure 3. MAST (top) and NIASG (bottom) in litter.

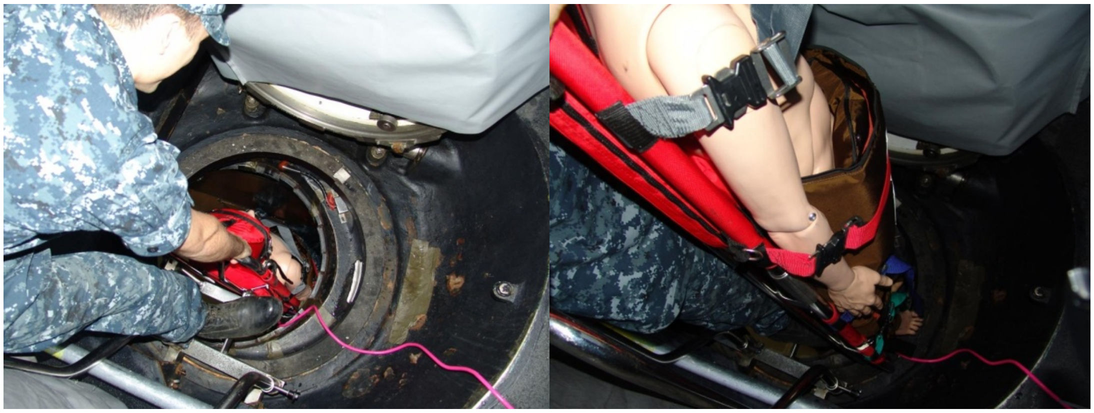

Figure 4. Extracting from the forward hatch with evident space constraints.

Figure 5. Transfer of mannequin/litter through submarine.

Figure 6. Haul-Safe Winch System (Spec Rescue International).

Figure 7. Submarine bridge, illustrating limited deck space for winch system.

RESULTS

Two main types of anti-shock garments were identified: pneumatic and non-pneumatic. Pneumatic anti-shock garments, also known as military anti-shock trousers (MAST), were obtained from the David Clark Company, Inc (Worchester, MA). Non-inflatable anti-shock garments (NIASG) were obtained from the Zoex Corporation (Ashland, OR).

Both the MAST and NIASG carrying cases were soft, lightweight, and approximately the same size (Figure 1). The NIASG had the advantage of serving as its own carrying case when folded, whereas the MAST's case was separate in order to house the inflation pump (Figure 2). Using a mannequin, all stretcher types (SAR litter, Miller board, Reeves Sleeve) were fit-tested and found to accommodate both the MAST and NIASG without difficulty.

Application time for the MAST was slightly longer (by approximately 2 minutes) than the NIASG due to the need to set up the inflation system, pump-inflate the trousers, and then seal off the connections. Achieving an even inflation of all compartments was difficult and the over-pressure valves did not appear to be functioning properly, which presents a risk of potential over-inflation, particularly upon air-evacuation by helicopter as air volume in the sealed garment would further increase with altitude. As it does not require inflation, the NIASG did not have these issues (Figure 3).

A mannequin fitted with anti-shock trousers was then evaluated for maneuverability through both compartments of USS Pittsburgh (SSN 720). Overall, maneuverability onboard a submarine is very limited due to space constraints, narrow passageways, and tight angles around ladders (Figure 4). These constraints are particularly evident in the engine room. Many areas require movement of the stretcher in all dimensions to accommodate angles and equipment (Figure 5). The stretchers currently employed onboard were found to accommodate both MAST and NIASG without difficulty. Further, no significant additional burden was added by the anti-shock garments with respect to transporting a stretcher-bound patient through the boat.

One potential hazard was identified with respect to the MAST usage in maneuvering through the boat. While it is very possible to use the inflatable anti-shock garment in casualty egress, there were several areas where sharp edges and other objects presented a tearing risk. (The NIASG did not present this problem.)

A group of local submarine independent duty corpsmen was assembled to provide investigators with feedback regarding the option of having the anti-shock garments available. Several mentioned having them onboard in the past, but none had actually used them. Storage was not identified as a major issue for either the MAST or the NIASG, however, the consensus was that the NIASG would be preferred as it did not require inflation equipment or have tear or volume expansion potential.

In addition to the anti-shock garment evaluation, a winch system to assist with casualty extraction from the hatches was also tested aboard the boat. The Haul-Safe Winch System was assessed for feasibility of use. This system weighs roughly 50 pounds and is adjustable in length from 60 to 96 inches. At an eight-foot center point height, it has a rated load capacity of 1000 pounds (Figure 6). One of the locking bolts on the tripod legs was found broken on delivery of the system, creating a safety hazard as there was no way to guarantee the leg would not slip during testing.

The Haul-Safe Winch was positioned over the forward and aft hatches without difficulty for use in extracting casualties. Unfortunately, due to limited deck space on the sail bridge, it could not be used to lift a casualty through the bridge hatch (Figure 7). In addition to limited space, stability would also be a potential issue with this device, particularly when it is raised to a greater height to allow a stretcher to clear the opening of the hatch. A sea state causing significant roll and pitch would be of concern in this instance. The bulk of the device would make it difficult to transport up the sail in a higher sea state, with considerable injury potential if the device were to fall.

DISCUSSION

This evaluation of the use of anti-shock garments onboard a U.S. Navy submarine found no major impediment to casualty egress beyond the already identified constraints of moving through the passageways and spaces. Storage space onboard is limited for medical, as with all, supplies. However, both MAST and NIASG are relatively compact and equivalent in terms of storage space required.

In comparing the MAST with the NIASG, several advantages to the NIASG were identified. The NIASG was quicker and easier to apply as it did not involve the additional steps of setting up an inflation pump and tubing or time to inflate. Over-pressure valves in the MAST did not function properly in the model tested, presenting a concern for over-pressurization of the garment when applied to a patient. Such over-pressurization would be of particular concern should air transport be necessary, as pressure would only increase further with altitude due to Boyle's Law. (Having too much pressure in the anti-shock garments would greatly increase the risk for compartment syndrome and other medical complications.) Further, the MAST presented a tear risk in navigating tight spaces during egress from the submarine. Such a tear could lead to a sudden deflation of the device precipitating a rapid drop in blood pressure as well as a sudden increase in lactic acid burden to the patient being transported. Neither over-pressurization nor tearing risks were present for the NIASG. Other advantages to the NIASG included the ability to perform a rectal or pelvic exam with the device in place and the ability to allow for joint movement at the knees, if necessary. The NIASG has also been associated with fewer complications than the MAST, which fell out of favor due to the risk of compartment syndrome, lactic acidosis, and studies showing a lack of survival benefit for patients within 45 minutes of a major trauma facility[6,7,9,10].

The NIASG is a newer device which is still undergoing evaluation with randomized controlled trials in Africa. Information available to date, including prospective pre-intervention/intervention trials, have been positive and shown a 50% increase in survival and 50% decrease in blood loss for victims of postpartum hemorrhage in Africa where prolonged transport times and lack of immediate access to blood products present similar issues to those faced by the submarine force operating in remote environments[11,14,18]. No instances of compartment syndrome or lactic acidosis have been reported, despite some application times of 36 hours or more [16], most likely due to the lower pressures used by the non-inflatable garments. Further testing of this device in the setting of other etiologies of hemorrhagic shock would be beneficial.

At approximately fifty pounds and five feet in length when collapsed, the Haul-Safe Winch System was found to be cumbersome both in terms of transport and storage. It would be of potential utility for evacuations performed via the forward or aft hatches, but would be impractical for use via the sail. Suggestions for improvement would be a more lightweight design and/or materials as well as having a mechanism for anchoring the tripod to the deck during an elevated sea state. Designing an effective device for use on the sail bridge requires consideration of the equipment on the bridge for each boat class for optimal function and safety for the casualty and those conducting the rescue. Anecdotal reports and discussions with submarine independent duty corpsmen that have performed medevacs via the sail revealed that light-weight technical climbing gear, or similar equipment, would be the most useful for ascending the sail with a casualty. Further study of this particular area is warranted to develop a more standardized and safer approach to medevacs conducted via the sail.

Ideally, sail medevacs should be avoided if at all possible. The sail itself presents a safety hazard even before the additional complication of trying to lift a stretcher-bound casualty up to the sail deck. If, however, such a route is necessary due to sea state or other complication, protective padding for the patient should be provided to prevent further injury due to blunt trauma during hoisting. The hoisting mechanism should be designed to accommodate the design of the bridge deck, as space is extremely limited. Safety of topside rescuers is of concern during this operation in view of the potential for secondary casualty while trying to extricate the patient through the sail.

CONCLUSIONS

The use of anti-shock garments aboard U.S. submarines would not unduly impede casualty movement and egress from the boat. Further, newer non-inflatable anti-shock garments (NIASG) present several advantages compared to their older inflatable counterparts. Ongoing clinical trials of the NIASG should provide further information regarding their potential clinical benefit when transporting casualties from austere environments as well as pertinent risks associated with their usage.

The Haul-Safe Winch System was found to be unsatisfactory for casualty lifting on U.S. Navy submarine bridges but satisfactory in calm conditions over the deck hatches.

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